STATE OF THE ART REVIEW

OF HUMAN-HUMAN COLLABORATION RESEARCH:

AN INTEGRATED, MULTIDISCIPLINARY PERSPECTIVE

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Introduction

Teamwork has been essential to the military since the initiation of warfare. It is the enhancement of individual performance that makes teamwork a necessary tool for all military leaders There are problems to be solved that require the synergy achieved in a team setting with the sum solution being greater than the parts of the solution brought by each member of the team. The time required to do this problem solving, sometimes depicted as the "Observe Orient Decide Act (OODA)" loop is currently identified as the limiting factor in winning military action. The team who gets their OODA loop shorter than the other team's wins the war.

Seymour (2002) points out that what was once referred to as "teamwork" is now often named "collaboration". This change in terminology reflects the change in teamwork brought about by the technological advances that make it possible to work as a team without being physically together. Jamal and Getz (1995) also explored the concept of collaboration as a team with a stake in the outcome. Teams have traditionally required meetings to ensure that all the team members work together. This also entails travel requirements to get subject matter experts together to solve a particularly complex or difficult problem. In the current economic and technical environment, it is no longer desirable to get members of a team together for meetings. While face-to-face meetings are clearly quite useful, they are resources expensive (time, money, reduced productivity for other projects while traveling). Businesses have moved to more "distributed" meetings. By using technology, team members are able to communicate and meet without being in the same physical location. This has meant use of telephone and video teleconferencing (VTC). This use of technology allowed an emulated face-to-face meeting of people not collocated without travel. Early VTCs were cumbersome and difficult to adapt to, but have improved over time. Chandler (2001) highlights that it is technology that enables the improved utility of teams.

The military has adopted this technology as well and used it to good purpose. However, the military has an increasingly urgent need to pull teams together from personnel that are not only not physically collocated, but are distributed around the globe in such a way that there is no practical time to have a meeting. With 24 timezones, it is difficult to schedule a worldwide meeting that is easily accommodated by all participants. Consider that just in the contiguous US, there are four timezones. When one takes into account the normal work hours there are only a few hours available to schedule a meeting in this relatively small geographical region. When the military has personnel located across many more timezones, or personnel deployed to one timezone and military planners distributed through other timezones, the hard reality of planning meetings everyone can attend has to be faced.

There are a number of technological advances that will help move the military or businesses through the transition from synchronous (at the same time), collocated, face-to-face meetings to asynchronous (at different times) distributed (in different places) meetings where collaborators (team members) never actually meet. This new order for meetings is Asynchronous Distributed Collaboration (ADC). ADC is team members working together to solve problems that exhibit some urgency in a relatively short time span while never actually meeting each other personally.

There are a number of interesting concepts associated with ADC, but we will limit ourselves here to the cognitive aspects of the team members that will need to be supported by technology.

This literature review seeks to provide.information on significant issues that impact the success of ADC in a military domain. There are a number of interesting disciplines that may be related to aspects of ADC but are out of scope for this discussion. These include social psychology, sociology, anthropology, organizational small and large group behavior and organizational behavior issues related to differing rank of ADC team members. This review seeks to represent a number of disciplines each impacting ADC. These disciplines include: cognitive psychology, computer science, education, and management and organizational behavior. We tried to identify the significant ADC issues that emerged across the literature and provide a discussion of how these issues effect asynchronous distributed collaboration

The significant ADC issues are discussed within the context of a collaboration taxonomy. This taxonomy, presented below, consists of the major elements that make up successful collaboration teams. These elements would need to be present and/or supported regardless of the distribution of members in time or space (i.e. these elements would hold true regardless of whether the collaboration team meets face-to-face frequently with free exchange of ideas or only communicates via email at convenient times). The collaboration taxonomy is part of an overall conceptual model of collaboration, which is presented and discussed in Appendix C.

It is essential to remember that this work is scoped to reflect a team of highly skilled and appropriately experienced personnel distributed in space (around the globe) and time (in different not necessarily contiguous time zones) which prohibits face-to-face meetings. To further complicate the scenario, the members of the team have not met before and will develop their interactions in an asynchronous media.

There is a great deal of literature available in a variety of disciplines, but Asynchronous Distributed Collaboration is a relatively new area (Keisler and Cummings, 2002). The most pertinent literatures are from cognitive psychology (human information processing), computer science (collaboration technology), education (distance learning and collaboration), and recently geology (asynchronous distributed collaboration). However, the classic business literature has recently focused on teams due to the increase performance effects and lower cost solutions achieved by effective teams. As identified in the business literature (Doise and Mackie, 1981) there is little conclusive research on the mechanisms of social interaction and their effect on cognitive performance of individuals. This therefore results in few theories on the social factors on cognition. In addition, there are a number of social issues that effect individual cognition (and presumably group cognition, if team problem solving is conceived as group cognition). These factors include development of social behaviors, social status, and development of strategies for dealing with socio-cognitive dissonance or conflict. Another social factor that effects group or team performance and has had limited research is group size. Huberman and Loch (1996) highlight the effect of team size on organizational performance. They found that team size had a direct effect on performance that was related to perceived work of other team members. Other authors have also expressed the financial relationship of group performance and other business metrics (Buckingham, 1998, Finholt and Sproull, 1990, Malhotra, 2001).

There is a great deal of research on group performance however it has centered on social and social behavior concerns and were therefore out of the scope of this review. There is a nice collection of this research in Baecker's 1993 compilation of research pertinent to Computer Supported Cooperative Work (CSCW). CSCW was coined in the 1990s as computer interaction began to develop and the potential to use computers to improve human-human interaction was realized (Baecker, 1993)). These specific references include McGrath's (1984, 1991) treatment of time; Jay's (1976) identification of the significant functions of meetings (which functions should be replicated or emulated in a CSCW environment); Short, Williams, and Christie's (1976) presentation on the importance of visual communication in groups (functions that might need replication or emulation in a CSCW environment); and Viller's (1991) exploration of the role a facilitator would have on group performance in a CSCW environment. Baecker (1993) also includes an early treatment of case studies of cooperative work including Posner and Baecker (1992) exploration of collaborative writing, Tang (1991) observation of collaborative behavior, Nardi and Miller (1991) and Flor and Hutchins (1991) explore collaboration in software; and Kraut, Fish, Root, and Chalfonte (1990) explore informal communications. Separately, Harris and Figg (2000) also discuss the utility of facilitation in distributed groups.

Rawlings (2000) explored collaborative teams with respect to their ability to improve business bottom line. That is does teamwork contribute positively to business financial goals. She points out the difficulty of working across functions within an organization and the organizational challenges to team performance. She highlights the leadership issues associated with working in teams, including many social and organizational issues. She does point out important individual skills sets that are required to ensure successful leadership team performance. These include managing individual inputs in the context of team results, managing interdependencies of team members, sharing vision across members of the team, and team leadership that promotes "interdependent, collaborative initiatives that force cross-functional collaboration." Rawlings does make the case, though, that leadership teams are different from other teams. Work teams (as distinguished from Leadership Teams) require complimentary skills sets in members, common purpose (but not shared vision), shared performance goals and mutual accountability (but not individual accountability). Rawlings (2000) states that leadership teams exhibit collaboration. Further, she indicates that, collaboration is the process of shared creation: two or more individuals with complementary skills interacting to create a shared understanding that none had previously possessed or could have some to on their own. Collaboration creates shared meaning about a process, a product or an event. Rawlings also identifies the essentially social and linguistic nature of collaboration. Stahl (2000) also indicates that, "it is not clear in [the] literature which cognitive processes are involved in the collaborative knowledge building" it is unclear "what the relationship is of collaborative group processes to individual cognitive processes."

Another issue is the effect of not being collocated for team work. While the social processes may be different, there are probably changes in the cognitive domain as well. Rogers (1997) provides a tutorial on Distributed Cognition, which she defines as a "hybrid approach to studying all aspects of cognition, from a cognitive, social, and organizational perspective. The focus is on human cognitive activity as it is effected by social interactions. She points out that an important property of distributed cognition is "the distribution of access to information in the cognitive

system. Sharing access and knowledge enables the coordination of expectations to emerge which in turn form the basis of coordinated action."

Lohman (2001) examined the "governance of complex social systems, especially decentralized systems characterized by distributed information and dispersed decision-making powers" From her perspective in political science and the effect of group performance she also explored the effect of collective decision-making on communications and actions.

Much of the education literature has focused on the collaborative nature of learning. Again, the exhibition of social behavior appears to be necessary for successful incorporation of learning and knowledge in children (and presumably adults). Researchers such as Collins, Brown, and Newman (1989) have moved to approaches in learning such as "cognitive apprenticeship" which combines cognitive and social behaviors, Ding and Flynn (2000) and Goodman, Geier, Haverty, Linton, and McCready (2001) also explore collaboration in learning, while Neal (on line) relates the problems with the social aspects in conveying cognitive content when teaching at a distance.

Literature has also concentrated on distribution of people working together either in learning environments or work environments. Specific interest in distributed work has been explored by Kiesler and Cummings (2002) and Hendricksen (2002). Jensen (2002) provides insights from the user perspective including statements of user needs/desires and exploration of the virtual team from the military perspective along with an illustration of various collaboration technologies.

Much of the literature has focused specifically on the communication of ideas, the development of mental models and to a smaller extent the sharing of those models. Less cognition oriented work has looked at negotiation, clearly a social behavior, or at completion of actions identified in the decision-making phases of team collaboration.

The following sections will discuss the above literature and attempt to identify areas in which more research must be conducted. Note that there is a great deal of overlap in the taxonomy and in the literature. Some of the references may be cited in one area, but the findings and representative thinking from those references may apply to other areas in the taxonomy and will be mentioned where appropriate.

Military Requirements

The major requirement for collaboration in today's military is the ***ability to engage a heterogeneous, distributed team for quick response collaboration aimed at issue resolution, or Command of Action selection (i.e. decision-making)***. The type of environment that this team must operate within has the following characteristics:

- Asynchronous and Distributed Command Level Decision Making
- Asymmetric Warfare
- Dealing with Open-Source (Uncertain, Conflicting, Partial, Non-Official) Data
- Culturally Diverse Partners
- Short Turn-Around, High Stakes, Crisis Driven Decision Making
- Rapidly Changing Team Members and Associated Organizational Structures
- Operations with Joint, Coalition, Non-Government and Volunteer Organizations

Recent examples of such heterogeneous, distributed collaboration teams include:

- Multinational Response Team in Afghanistan
- International Humanitarian Relief Efforts
- Multi-Government Agency Sniper Hunt

The Department of Defense (DOD) Policy for this type of collaboration is specified in multiple sources including *DOD Joint Vision 2020*, which mandates interoperability for the Joint Force of 2020; the *Naval Transformation Roadmap*, which requires a networked, jointly integrated, sea-based power projection force, assuring coalition and joint force access and protecting America's interests anywhere in the world; and *FORCEnet* , which is designed to develop a highly adaptive human-centric system to convert information into actionable knowledge to improve situational awareness that will enable dispersed, human, decision-makers to leverage military capabilities to achieve dominance with joint, allied and coalition partners.

To achieve this type of collaboration specified by DOD requires the use of *integrated collaboration tools*. Jensen (2002) describes the requirements that need to be supported by various collaboration tools in order perform effective collaboration in the types of environments described above. Jenson also describes the limitations of the current tools and states the need to define the specific requirements for each stage in the collaboration process and identify those tools, which can support those stages. Once the tools are identified they need to be integrated into a tool environment that can be used by the various coalition teams. The tool environment should be designed to permit easy integration of new collaboration tools as they are developed.

A Taxonomy for Collaboration

Classification of information is a useful method to ensure understanding of the concepts in a new area of interest. Asynchronous Distributed Collaboration (ADC) is emerging as an area of interest in a number of fields including computer science, psychology, sociology, anthropology, business, and organizational behavior. The literature is pulled from a number of areas including cognitive psychology, computer science, education, and management and organizational behavior.

Developing a taxonomy allows researchers a framework on which to base their thinking. This framework provides a platform from which to arrange new information, especially when the information comes from divergent disciplines. The taxonomy under consideration is designed to support a cognitive approach to synchronous and asynchronous distributed collaboration. It focuses on the general categories of activity, primarily cognitive, that supports collaboration in relatively small heterogeneous groups. There are five elements in this taxonomy. Those elements are:

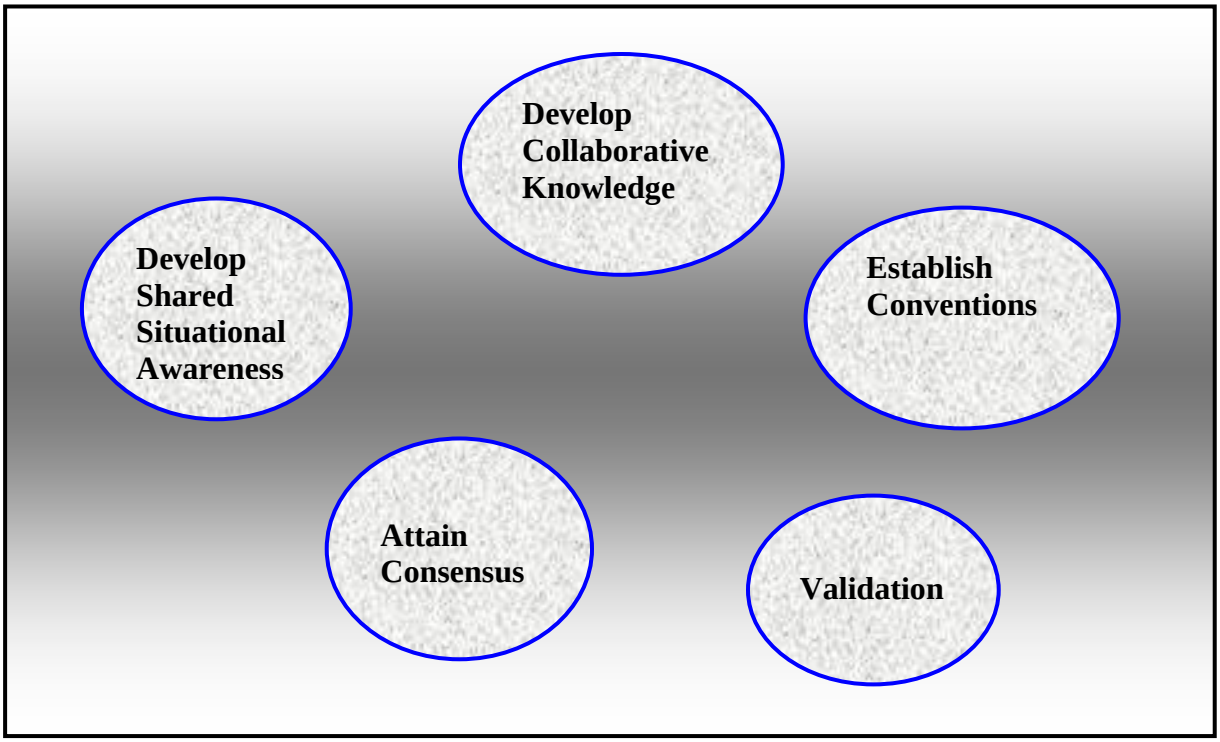
(1) Establishing Conventions for Communication within the Collaborative Group
(2) Developing Shared Situational Awareness and Understanding
(3) Developing Collaborative Knowledge and Trust
(4) Attainment of Consensus Through Negotiation
(5) Validation of the Collaborative Solutions.

Figure 1 illustrates the taxonomy. *Establishing conventions for communication* consists of the team developing rules for team behavior, terminologies and tools for consistent transfer of meaning, and individual mental model development. *Shared situational awareness and understanding* consists of the team coming to agreement with the facts of the situation, recognition of but not acceptance or resolution of differences or perspectives. *Collaborative Knowledge and Trust* consists of the team having a common understanding and agreement of corporate and individual goals and capabilities, being able to negotiate different perspectives resulting in deeper understanding of proposed solutions / actions, and development of trust between team members. *Attainment of consensus* consists the team identifying and negotiating differences and achieving a common outcome agreed to by the complete team. *Validation* consists of the team testing the effectiveness of the proposed solutions / actions, revising the solutions / actions based on tests results, what –if analyses and producing final solutions / actions.

While there is no method to illustrate the elements of the taxonomy without an implied time element, it is important not to infer a time element. All the elements of the taxonomy are related to one another. These interactions are not orthogonal nor are they relational. It is assumed that team members are acting primarily in one element but that other elements may also be present in team behavior. There is an implied flow down in the figure and in the naming of the elements, but that flowdown is not presented because there is no order to the elements in the taxonomy. These elements occur in a number of orders and have multiple, nested interdependencies. The elements occur as required for each team that participates in the event space.

The remainder of this literature review will summarize the relevant literature in each of these taxonomic elements, describe the findings across disciplines and identify areas for future research that would be relevant to the establishment of successful military adaptation of asynchronous distributed collaboration.

Figure 1. Elements of the Collaboration Taxonomy



ESTABLISHING CONVENTIONS FOR COMMUNICATION

Communication between people has been extensively studied as the basis of teamwork and collaboration. It is the keystone of transmission of information between people and can occur in a variety of media. Weather spoken, written or drawn (in the case of electronic whiteboards and the like) people attempt to share their ideas via communication of some sort.

The preponderance of commercial work in development and marketing of computer supported collaborative work and computer mediated communication has focused on causing communication to occur between people regardless of their dispersion in time and space. These tools are discussed in their own section below.

A distinction can be made in the literature, between synchronous communication (which is our traditional approach) and asynchronous communication (which is a relatively new type of communication, and therefore has not been studied as much). We will begin with traditional, synchronous communication and then proceed to asynchronous communication.

Communication is critical to human social behavior and is challenging to explore precisely because that exploration occurs via the medium under study. The use of different mediums makes any exploration of communication challenging but not impossible. The basic quality and utility of various communication mediums is presented in the general literature and hardly requires treatment here. Riva and Galimberti (1998) discuss the requirement for a change in *metaphor* for communication as we move from synchronous, face-to-face interactions to support

work to distributed, asynchronous interactions for working. Again, however, they stress the social interactions of communicators rather than the cognitive behaviors of those communicators.

Communication occurs at different levels for different reasons. There are formal and information communications within and between teams. Not all the pertinent information is passed in formal communications. What becomes important in ADC is determining what is communicated how and how that can be simulated or emulated in an ADC situation. Jones and Kasif (2002) point out four generic human communication tasks: synchronization (turn taking), coherence, repair (correcting incorrectly received information), and shared focus (of group members). These social behaviors clearly have cognitive components, but they are not specified.

Baecker (1993) pulled together a great deal of important thinking on communication with respect to computer-mediated interaction. This collection of works is a seminal contribution to the literature because it is multidisciplinary and.covers the major issues in computer-mediated interaction. In this collection are useful works including Kraut, Fish, Wood, and Chalfonte (1990), Dourish and Bly (1992), Heath and Luff (unknown), and Hollan and Stornetta (1992). Kraut, Fish, Wood, and Chalfonte (1990) explored the informal communications that occurred in organizations. They found that informal communications comprises over 85% of interactions. These communications were quick and spontaneous with about half of the 85% occurring without either party entering the situation thinking they would have the conversation. Kraut et al (1990) highlight the many uses of informal communication in pursuing the goals of the group including providing momentum to collaboration. Dourish and Bly (1992) also explored informal communication and its support via tools. They used "portholes" to provide a level of awareness to users. They found that building awareness was useful, although they found it most useful for collegues to locate one another to engage in co-located informal communication .. They propose using portholes as a tool to help users in virtual environments. Heath and Luff (unknown) also explored people interacting, especially gestures and found that video interaction help mitigate problems interacting. Other researchers explorations of informal communication cited in Baecker (1993) include Hollan and Stornetta (1992) who looked at the issue of face- to-face communication and concluded that a thorough needs analysis is required to determine what should be simulated or emulated and what really must be present for communication to occur symmetrically.

Freeman, MacMillan, and Serfaty, (2002) have focused on the sharing of information via observation. They indicate that group members that are distributed will require tools to support that observation including representation to others.

Wilkes (1997) does a credible job indicating how cognition, a private event that is developed via social interaction, can be dealt with. Because there is no way to characterize group events in individual terms, he highlights Moscovici (1988) who argues for a change in looking at knowledge as an individual possession and instead use a "reference to the collective representations shared by members of particular social groups" Wilkes (1997) also cites Gergen and Gergen (1991) who proposes that all knowledge must be understood in light of "social constructions arising out of the dynamics of social exchange."

Lohman (2001) also indicates that people communicate private information, which is collected in group communication. Clark, Hori, Putnam, and Martin (2001) state that collaboration requires that people make private memory public and that the presentation be in a way that can be "sensibly evaluated". Godbout (1995) presents representations as being indexicalized like language is. That is, the social network helps develop language that promotes enculturation.

Transactive memory is "various categories of individual understandings in terms of their relationship to the understandings of other team members" Each team member is responsible for their knowledge and responsible for knowing "who else in the team knows what and how to access it, private knowledge that each person needs to show when relevant, 'meta-knowledge' about the adequacy and uses of knowledge, and team consensus knowledge, a repository for what the team has agreed to." (Noble, 2002).

Wilkes (1997) also proposes that "if transactive memory is to work effectively, each participant needs to know which component knowledge is currently being held by others, and this means that directories for indexing this information will need to be created and constantly updated." This would work well in the proposed system in that each member of the military planning team would have their own specialty so other members would know who would be responsible for knowing/remembering what technical areas, thus sharing memory in a way that the group forms rather than in a method imposed.

Stahl (2000) indicates that communication results in mutual understanding if communicants participate in discussion openly. She states that collaboration occurs where people use communication to "mediate between personal belief and accepted knowledge." Again, we verge onto social behavior rather than cognitive behavior. She also supplies a tool, the collaborative Knowledge Building Environment, which diagrams knowledge building in which personal beliefs are communicated via computer media. Stahl proposes a computer based discussion medium, which occurs asynchronously but allows groups to participate in development of the collaborative knowledge. She highlights the importance of share word meanings to shared understanding (more in the next section on shared understanding). Tversky, Zacks, Lee, and Heiser indicate that graphics are another communication medium that has developed in social interaction and that most effective graphics have been developed interactively by communities of users over time. In the process, they become schematized, often reflecting cognitive structures that parallel structure in language. Graphics use elements and the spatial relations among them meaningfully, forming a rudimentary semantics and syntax respectively. The end result being common underlying cognitive principles in the use of space and the elements to convey meaning. Tversky et al also explored the use of graphics to represent private ideas for consumption by others in a collaborative group. Graphics allow " a community of users to share the same conception and to use it in inference and decision making." They propose maps as a representation of natural collaboration.

However, when we move to communications that are distributed in time, there are still questions. McComb reports that successful teams put a great deal of effort into developing a convention. This is true in face-to-face teams and will probably hold true for distributed teams. Benford, Greenhalgh, Rodden and Pycock (2001) report that this is likely. They found that presenting different users the different perspectives of the same view hindered people's ability to

collaborate. Godbout (1995) suggested that representation of information was indexicalized like language which meant that the perspective of the conversation was clear. When team members distribute though, this indexing was lost and meaning became harder to share. This highlights the importance of the shared environment. He indicates that the social network of the team is what helps develop meaning and therefore shared understanding. Godbout states,

> "The role of narratives and conversations is perhaps more complex than might first appear. An intriguing role in learning is placed by 'legitimate peripheral participation,' where people who are not taking part directly in a particular activity learn a great deal from their legitimate position on the periphery. It is a mistake to think that important discourse in learning is always direct and declarative"

Cummings, Butler and Kraut (2002) reviewed the quality of online social relationships and found that people had tighter relationships with people they communicated with in multiple modalities rather than one distance communication. They suggest that the social nature of relationships will be lacking which could impact the collaboration of the team given the social nature of team interactions in face-to-face environments and the current inability to recreate those interactions in distributed environments.

In ADC there is even less research looking at the communication cognitive requirements. Again, research has focused on the social nature of interaction. Cristian (1996) looked at the need for a common framework (convention) to explore synchronous and asynchronous communication. Eveland and Bikson (1998) studied two similar teams attempting to solve the same problems. They found that a computer-supported team solved the problem like the unsupported team, coming up with the same answer but using very different conventions. Keisler and Cummings (2002) looked at proximity and suggest that communication technology helps both cohesive and noncohesive teams but is more helpful to those teams who are already communicating. They discuss the importance of "social distance" to developing teams. Again, there is no discussion of the cognitive aspects of communication or convention on team collaboration.

Alterman and Garland (2000) speak to convention. They point out that joint activity requires some convention, which is a result of common ground. These conventions arise from the solution of recurring problems, and develop social interaction that allows the team to perform. Communication is the activity that supports the development and instantiation of conventions. Alterman and Garland speak to specific memory components for individuals, and again, relate that cognition to social behavior. These conventions only occur after iterative interaction. This occurs for face-to-face teams, but again, there is limited social interaction to allow this development of conventions to occur in ADC. It is not clear from their model what computer mediated activities would facilitate the development of similar conventions.

Gaps/Areas for Future Research

The gaps in understanding the role of communication and establishing conventions are:

(1) Identification of the major requirements for establishing effective communication.

(2) Determining the role of informal and formal communications in face-to-face and in ADC communications situations.

(3) Determining how face-to-face and ADC communications are alike (and therefore require emulation) and the ways in which they are different (and therefore require different collaboration tools and support).

Developing Shared Situational Awareness and Understanding

While the debate continues nearly twenty years after the introduction of situational awareness, there is a definition that most researchers adhere to: a person's mental model of the current state of a dynamic environment; the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future (Endsley, 1988a). In team collaboration, team situational awareness is established through the development of a team shared mental model. A shared mental model is defined as organized knowledge that members have in common regarding the task. Johnson-Laird (1983) made a strong case for mental models as a method for collecting information and using it in individual cognition for the distribution of information for action via cognition. Wilkes (1997) builds a case for mental models referring to literature, including, Franklin and Tversky (1990) who speak of a cognitive framework that people use when interacting with other people. Intons-Peterson and Roskos-Ewaldson (1989) indicated that mental models exist somewhere between cognition and perception. The apparent ubiquity of the mental model in the research makes it prime for use as a means of conveying cognition between members of a team. This model is probably best conveyed graphically (Tversky et al).

Nosek (2001) uses the concept of sensemaking to convey similar information. This is especially true in new or complex situations. Sensemaking can apparently be conveyed to team members as well. Nosek indicates that all members of a team must be on the look out for relevant information to ensure the team mental model is shared effectively. There are again a myriad of social issues bound up in generating this shared mental model, which must have individual cognitive components that require study.

Stahl's (2000) approach uses personal beliefs from individual perspectives to generate group understanding of a shared mental model. Her knowledge building environments act as a tool for sharing these models.

McComb also builds on mental models, which represent cognitive activity to other team participants. These mental models explain and describe individual cognition. McComb cites Cannon-Bowers, Salas, and Converse, 1993 who stated that "shared mental models are knowledge structures held by members of a team that enable them to form accurate explanations and expectations for the task, and in turn, to coordinate their actions and adapt their behavior to demands of the task and other team members." McComb makes the case for a team mental model as well which represents the thinking of the team. These team mental models are based on common experiences and iterate as required "until they converge on a point that allows the team to function as a collective." The information in the shared mental model helps team

members cope with the team work. McComb indicates that team members must continually evolve both their internal mental model and that held by the team.

Hurley (2002) indicates that collaboration includes synergy of sharing both tacit and procedural knowledge. He cites Nonaka and Takeuchi (1995) (also cited in Malhotra, 2000) who elaborate knowledge sharing as a socialized process for converting knowledge.

Benford, Greenhalgh, Rodden and Pycock (2001) review the user of collaborative virtual environments where avatars represent team members and may support social interaction in space. They indicate that virtual physical presence does not solve all representation problems, but certainly a virtual environment is a possibility to support the tools for ADC shared mental model building.

Clark, Hori, Putnam, and Martin (2000) explore "group cognition" by studying group memory task performance. They do not report collaboration in group memory tasks. They do point out a social problem with group cognition in their finding that personality and compellingness overcame individual cognition, which suggests that the collaboration, perhaps even in ADC will have greater social components than cognitive ones. Rawlings (2000) points out that the team has to have a shared understanding of the problem to develop collaboration. This again requires conversation among the team members so they can build a shared model of the problem and their own organization. Here the social and organizational behavior aspects of the team arise as the make up of the team and its internal organization will be dictated in some measure by their understanding of the problem. These conversations will elicit individual's mental maps as fodder for the development of the shared mental model. Rawlings points out that "when teams reach the point of clarity about goals and shared outcomes, individuals find themselves at the intersection of their personal commitments to their respective goals and their commitments to the collective good of the organization and the success of others. Collaborative conversations occur when individual team members put aside personal agendas to address the needs of the team and the organization."

DeVega, Manual, and Marchark (1996) have another interesting aspect to shared mental models. They point out that mental models hold the representation of pronouns. Pronoun use is particularly difficult in ADC as users, especially in email, make poor use of referents with frequent use of pronouns. They point out that how speakers generate verbal descriptions of spatial configurations suggests the construction of the cognitive maps in listeners.

There are a number of approaches for team mental model development for solution of team problems. Authors such as McComb, McNeese, Murdock and Aha (2002), Noble (1999, 2002), Geisler (2002), Denzau and North(2002), and Langston, Kramer, and Glenberg (1996) have used a mental model approach to determine team cognition as represented in shared mental models. Rogers (1994) uses the representation of distributed cognition rather than mental models as a means of generating a framework for the concept of shared cognition in teams.

Sycara (1998) indicates that successful teams are different from unsuccessful teams in that successful teams exhibit team self-awareness, interdependence, performance monitoring,

feedback, communication of intention, and aiding teammates. These are social activities that impact team collaboration.

Dourish and Bly (1992) explored "portholes" as a means of providing "awareness" to distributed team members. This media space used video to generate an environment for awareness. Benford, Greenhalgh, Reynard, Brown, and Koleva (1998) focused on virtual reality as a means of generating an environment in which team members might develop shared mental models. The environment was designed to support communication between members. They compared the actual physical environment and the virtual physical environment. They found the "lack of globally integrated spatial frame" and "asymmetrical awareness" of the two environments resulted in two, unshared frames of reference. They developed a "mixed-reality boundary" to reduce separation which shows promise but requires further investigation.

Gaps/Areas for Future Research

Again, much of this work has focused on the social interaction, communication, and methods for individuals to produce an overt representation of their covert cognitive behavior. The hope is that the generation of overt representations will allow individual's to discern if there is general agreement across individuals' covertly held representations of their cognition and agreement with the team's shared representation. To facilitate these types of representations the following areas need additional research:

(1) Development of collaborative computer supported tools that facilitate development of team shared mental models.

(2) Exploration of other environments to support collaboration. Whether communications based or virtual reality based, there is a need to determine the environmental requirements necessary to support the social interactions to develop effective collaboration.

(3) Development of metrics for measuring the team's shared mental representation. These metrics need to be incorporated into the computer supported tools that facilitate team shared representation.

Developing Collaborative Knowledge and Trust

The assertion of common ground is purely social, as is the concept of trust. However, there have been some inputs that have a cognitive component. Common ground refers to shared referents in communication (Clark and Brennan, 1991). This process is iterative and necessarily continuous. Their concept of grounding is central to establishing common ground. Grounding is the feedback loop that ensures both participants' meaning is complete. Grounding has different aspects depending on the communication medium in use. If grounding is to be supported its requirements and functions will have to be identified. Cramton (2001) also supports the notion of common ground. Common ground must be established to ensure that communication by both parties are comprehended successfully. The establishment of mutual knowledge includes not

only the information but also its successful receipt. Neal (unknown date) talks about storytelling as a means for conveying common ground in an educational setting. She highlights Norman's (1993) concept that stories are "important cognitive events of particular pedagogical value because they encapsulate into one rhetorical package four of the crucial elements of human communication: information, knowledge, context and emotion. She also identifies that in asynchronous storytelling/education, the distance in place and time aids those students who do not wish to "speak up" while the storytelling component provides a platform for dialog and sharing. This is important in that it begins to explore the requirements for successful ADC and tying the requirements from collocation to those for ADC, which is lacking. Other researchers in distributed education have also looked at various environments to promote learning, including Goodman, Geier, Haverty, Linton, and McCready (2001) who promote a rich communication and a common workspace for both synchronous and asynchronous students; and Ding and Flynn (2000) who look at the development of collaboration skills with respect to their development of cognitive skills.

Wilkes (1997) discusses how people learn their limitations with respect to individual cognitive processes in a social context, which allows them to recognize that they can be supplemented by the team's activity. He talks about cognitive structures best understood at the social level. He calls these 'social representations" and they provide structure for team communication because they are shared. Further, Wilkes states that "social representations provide…means of accommodating unfamiliar events….allow for a degree of social consensus to be created…"

Noble (2002) discusses another concept for the generation of the team's shared experience. He refers to "team hardening" which occurs in new teams as they become used to one another. Stahl (2000) refers to the same sorts of behaviors when she discusses personal skills (summarization, text understanding, critical thinking, logical structuring of arguments, turn-taking, repair of misunderstandings, rhetorical persuasion, interactive arguing), which support collaboration. She also discusses "artifacts" which preserve meaning and understanding within the group.

Nosek (2001) when speaking of sensemaking discusses development of team knowledge through elicitation (asking questions) and the importance of this activity in collocated and distributed environments. Cummings, et al (2002) also reviewed the usefulness of the internet for the development of social relationships. They found that on line relationships were characterized by lower participation and communication than collocated social relationships. They also found that social interaction was different than work interaction on line.

Numerous authors have considered communication as it relates to shared understanding. These include Godbout (1996), Brock (2002), Bankes (2002), Lawless (2002), Madni and Lin (2002), Arnseth and Solhein (2002), Stahl (2002), Sternberg (2001), Gardenfors (1998), Orasanu (1992), Yufik and Georgopolous (2002), Diskell and Salas (1991), Alterman (2002), Funk and Miller (2002), and Hayne, Smith, and Turk (2002).

Salas, Prince, Baker, and Shrestha (1995) studied situational awareness in teams. They pointed out that team situational awareness is not the same as the summation of the individual situational awarenesses, but rather included unique activities such as coordination and information sharing. They highlight the distinctions between individual activities (which they call taskwork) and team

activities (which they term teamwork). Their results indicated that teamwork consisted of a set of stable behaviors and cognitive processes, including the sharing of individual representations of the task. They point out the importance of measuring the requisite shared mental models as a measure of team situational awareness. Similarly, Cooke, Salas, Cannon-Bowers, and Stout (2000) found that multi-person tasks demanded complex cognitive processing from the team of operators. These team models are held by all members of the team and must exhibit significant overlap and heterogeneity. They do measure cognitive aspects of team behavior and conclude that team knowledge is central to performance.

Trust is another aspect of shared understanding and results from knowing that team members have forming opinions of their performance in the group. Sheppard and Sherman (1998) discuss the element of trust as being the assumption of risk. They highlight that trust exists at some level in all relationships. Lachman (1998) highlights that effective collaboration requires trust that tasks will be assigned to the team member most able to perform the tasks. He suggests a standard task analysis will suffice in this effort. Favreau and Mills (1996) talk about risk with respect to knowing and feeling confident about the identity of the person with whom one interacts (in asynchronous interactions). In their book on Virtual Teams, Lipnack and Stamps (2000) devote an entire chapter to trust. They stress the social activities related to trust including the rapidity with which teams form when trust is not an issue. They point out that trust is more difficult to develop in virtual teams because of the lack of collocation. Lipnack and Stamps focus on the specific activities that must be instantiated in an ADC team to ensure the activities, which are easily accomplished in a collocated group occur or are at least attempted. These key activities are (a) the team needs to trust each other, (b) trust is built for each team member, (c) trust is based on each team member participating fully in the team, and (d) confidence in a team member's integrity and fairness comes from past experience with those team members. Lipnack and Stamps do not devote a great deal of time to the cognitive activities required to ensure or improve trust in ADC teams.

Gaps/Areas for Future Research

There are several gaps in the collaborative knowledge and trust area that require additional research:

(1) Better quantitative methods for measuring team knowledge.

(2) Improve techniques for measuring dynamic shared understanding within a team.

(3) Identify the requirements for collocated teams to perform and develop shared understanding and trust. These requirements will aid in the requirements for computer support tools that facilitate shared understanding and trust in ADC teams.

Attainment of Consensus

Negotiation is variously defined as conference with someone to come to an agreement or to bring something about through conference, discussion or compromise (Miriam-Webster online, 2002). This explicitly refers to a social interaction. As such, there is little exploration of the cognition of negotiation in the literature. However there are a few appropriate references.

Wilkes (1997) indicates that people are not likely to come to the same belief or conclusion even if they have experienced the same event. This can quickly devolve into a semantic discussion. What is meant by "experience" and event, for example. Rather, Wilkes points out that the researcher cannot assume that two people who are present at the same place at the same time will experience the same thing or that they will operate cognitively on that event in the same way, nor is it likely that they will result from the event with the same set of memories. He does cite Moscovici (1961) as arguing that traditionally knowledge as the "private possession of the individual" that must be "supplemented by reference to the collective representations shared by members of particular social groups". Wilkes further cites Gergen and Gergen, 1991 who hold that "all forms of knowledge are to be understood as social constructions arising out of the dynamics of social change." There is more discussion of this at shared understanding and models.

McComb (2002) states the case for mental model sharing necessitating reconciliation of differences in those models. Clark, Hori, Putnam, and Martin (2000) also indicate that there is a social component to remembering, especially if there is disagreement in that memory. Stahl (2000) also supports the collaborative social understanding of cultural artifacts that have shared meaning for all members of a group. Nosek (2001) suggests that members of groups have to "face the existence of multiple and conflicting interpretations" which requires that individuals: scan for and filter relevant information to create and maintain a sufficiently shared mental model to act effectively as possible. Shared mental models have the problem of knowledge or truth maintenance in that the information that was true for yesterday (or even an hour ago) may have decayed, have subtle changes, or may have demonstrably changed. These changes occurring over the entire decision space can play havoc with meaning, interpretations, and choice of actions, and highlight the need for conflict resolution, multi-source sensemaking, and the social construction of knowledge [Nosek & McNeese, 1997].

Mills (2002) indicates that communication in ADC is key to successful negotiation for issues related to organization, planning, and control. He states that negotiation is the activity that is key for human-human collaboration and therefore key for all CSCW, CMC or other tools sets that would support ADC.

All these researchers have explored individual experience of shared information, but the unresolved question is how individuals participate in group negotiation to establish that shared memory. While negotiation is a social behavior it, of necessity, must have cognitive components. Exploration of these cognitive components of social behavior would indicate the types of computer or agent support required in ADC negotiations.

Gaps/Areas for Future Research

There are several key research gaps that need to be addressed in the consensus area:

(1) Explanation of how individuals participate in team negotiation to reach consensus in an ADC environment.

(2) Identification and description of the cognitive processes used during team consensus building in an ADC environment. These cognitive elements would suggest areas for agent based support during ADC.

Validation

This area of the taxonomy has the least representation in the literature of cognition, computer science, and learning. That may not be surprising as each of these areas might see this element as the natural execution of activity in the other four elements. This element has more to do with social behavior and the overt behavior of individuals.This is the element in which team members negotiate between the various solutions and determine which of the solutions will provide the best answer to the problem.

Wilkes (1997) devotes an entire chapter to social cognition. He defines social cognition as "the manner in which we construe the thoughts and actions of other people against the backdrop of our own plans and goals." He then goes through a number of cognitive constructs and defines how each one is a type of social interaction. Godbout (1995) explores people solving problems in a framework. He mentions, "The problem, the solution, and the cognition involved in getting between the two cannot be isolated from the context in which they are embedded." Again, the overt behavior is established as a metric for covert individual cognition. The application of social behavior as a metric for covert individual cognition is intriguing and Wilkes (1997) makes a cogent argument of the inclusion of these techniques to more fully explore the problem space that is ADC.

Gaps/Areas for Future Research

These literature suggest that a broader approach than straight cognitive science will be necessary to explore the social behavior exemplified by negotiation, analysis and action performed under the validation step. This literature is represented in the social psychology and sociology literatures, which were out of scope for this review. In order to effectively address the validation step of the collaboration taxonomy the following areas need further research:

(1) Identify the behavioral processes involved in dynamic team negotiation both face-to-face and in ADC (if available)(social psychology / sociology).

(2) Identification of tools for performing sensitivity analyses of team solutions (social psychology, business literature).

Tools

As people increasingly work in teams and spend more time working together, the primary challenge for researchers is to identify what tools are required to generate an environment in which people can work together (Mills, 1999). The interaction of team members distributed in time and/or space requires extensive use of tools for sharing of information and to coordinate tasking and efforts. Tools will generate and support that environment. Some tools are historic and commonplace including telephone, fax, and email. However, with increasing distribution in time, and its concomitant increase in more asynchronous interaction, the tools of necessity must support not only information distribution and sharing but may also be called on to act as the medium of interaction, to fill the interstices of the team as it were. Seymour (2002) identifies group interaction as multidirectional communication along with team members' awareness of each other in the group. To achieve this awareness, tools are requisite.

Much of the work in tools for collaboration comes from the open literature on technology. There is a great deal of energy, not all of it directed, to find tools that are salable to organizations that need to solve team issues such as distribution and interdisciplinary teams at disparate locations working on design problems together.

What is missing is research on how people select and integrate the modalities available in face-to-face communication (Olsen and Olsen, 1994) and research into how to emulate the information transmitted in these modalities (Noble, 2002). Noble proposed a taxonomy, but it has limited utility without the requisite research to illuminate which behaviors must be supported (Noble, 2002). Mills (in press) also indicates that the time dimension (synchronous vs. asynchronous work) will drive tool support requirements.

As mentioned above, not all the tools that support distributed team work are new. Telephones, faxes, and email have served well the establishment of distributed teams. These tools require support though, when teams begin to be distributed in time. There are a number of tools available that support synchronous and asynchronous team work. Seymour (2002) identified 615 commercial, off the shelf tools and collaboration related services. Approximately 20% of those tools were available at no charge. These tools are marketed variously in support of distance learning, distributed collaboration, and computer supported collaborative work. Table 1 illustrates some representative tools types available and their major contributions. Table 2 illustrates some specific tools that are available and their features. The tools in tables 1 and 2 are not an exhaustive list and is not intended to replace the trade studies that would be necessary to establish the hardware and software requirements necessary to support asynchronous distributed collaboration.

Tool Capability	Synchronous/Asynchronous	Features	Deficiencies
Instant Messaging	Synchronous	Development of "communities of practice"	Does not require appropriate checks/balances for higher level decisions
email	Asynchronous	Allows detail sharing of information	Uncertainty of communication, limited data sharing capability
Internet Relay Chat	Synchronous	Chat rooms	Maybe unwieldy to search
Voicemail	Asynchronous	Verbal communication is easier for participants	Uncertainty of communication
MUD (Multi User Dungeon)/MOO (MUD Object Oriented)	Synchronous	Creates a "meeting place"	Cumbersome to use
Project established web pages	Asynchronous/Synchronous	Forum for sharing information files	May have configuration control problems
BLOGs (Web logs)	Asynchronous	Create community, easy to use, supports large groups of users	
Vizard	Asynchronous	persistent visualization	In development

Table 1: Representative Types of Collaboration Tools

Tool Name	Manufacturer	Features
Electronic Notebook	Oak Ridge National Laboratory	Shared files, remote access, easy search, includes hyperlinks and hypermedia
SenseMaker3	Stanford University	Uses multiple views of data
NetMeeting	Microsoft	Virtual synchronous meeting room with video capability and audio supplement
Exostar	Exostar, LLC	Electronic marketplace developed for aircraft manufacturers
Notes/Sametime	Lotus	Modular embedded components of line business tools (calendaring, email, chat, application sharing
Theatre Assessment Profiling System's Valuated State Space (TAPS-VSS)	Natural Selections, Inc.	Wargaming tool
Collaborative Object Workspaces (COW)	Temple University (download)	Integrates multiple tools synchronously or asynchronously
Global Network	Raging Knowledge	Access expertise via inquiry response system
IP TEAM	NexPrise	Manages communication, documents, messages and supplier data
Collaboration Server	Stellent, Inc	Secure ad hoc online team work
V6 Multisite Content Manager	Vignette Corp	Multisite and portal creation tools
Interwoven 5	Interwoven Inc.	Content processing, collaboration, management, intelligence, production and distribution
Groove Workspace 2.1	Grove Networks, Inc	Desktop collaboration
Conference Center 2000	PlaceWare	Web conferencing, application sharing, whiteboarding
TeamFlow	CFM	Project management, document management
Centrae Meeting	Centra	Web conferencing, application sharing, whiteboarding, voiceover IP
Caucus Virtual Team	Caucus Systems	Project management, threaded discussion boards
CrossPad	A. T. Cross Co. (Cross Pen)	Combines regular paper and digital pen for data capture
Natural Writing Board	Pegasus Technologies	Captures standard marker inputs digitally
Chandler	Opensource	Interpersonal information management, email, calendaring, contacts, data without server

Table 2: Representative Collaboration Tools.

Appendices

Appendix A: Centers of Excellence

As part of this literature review an extensive search was performed to identify centers of excellence in the area of human-human collaboration as it pertains to the objectives of the Office of Naval Research Collaboration and Knowledge Management (CKM) program. The criteria for selection were:

(1) what type of collaboration research are they doing (i.e. areas relevant to CKM)
(2) how long have they been doing this research
(3) how many staff members
(4) research focus: cognitive / computer science / social psychology / etc.(emphasis on cognition)

Centers of Excellence:

1. **E-Collaboration Research Center (ERC) - Fox School of Business and Management, Temple University** (<http://epi.temple.edu/erc/>)

- Type of collaboration research - their main goal is to conduct high-impact and theory-based research on e-collaboration that can be used by developers and users of e-collaboration tools
- Have been doing research since 1999
- The staff consists of 16 people including faculty and students
- Research projects focus on 3 main areas (pertaining to: organization, design, social psychology);
  - Organizational behavior and e-collaboration tools - projects in this area investigate the success of organizational development approaches related to e-collaboration rich environments
  - E-Collaboration tools and collaborative tasks - projects in this area investigate the impact of specific collaborations tools on certain types of collaborative tasks

E-communication tools and disease treatment - projects in this area investigate the use of certain e-communication tools in the treatment of social anxiety disorde2. 2. 2

2. **Distributed Systems Department Collaboration Technologies Group in the Computing Sciences Organization at the Berkley Lab** (<http://www-itg.lbl.gov/Collaboratories/>)

- Type of collaboration research - their goal is to research, develop, and deploy the middleware and technologies needed to advance distributed collaborative environments
- Have been doing research since mid 1990's
- The staff consists of 7 people
- Research projects focus on 3 main areas (pertaining to: computer science);
  - Collaboration tools - design of applications to support formal and informal real-time collaboration between geographically dispersed researchers
  - Communication protocols - investigating reliable group communication methods
  - Network-aware middleware - investigating middleware which enables network-aware applications

3**. Multi-Disciplinary Collaboration Project is a Joint Effort Among Researchers from 3**

Universities, Carnegie Mellon University, The University Of Arizona, and Stanford University (<http://www.multi-collab.org/>)

- Type of collaboration research – their research objective is to investigate collaborations within and among disciplines, groups and organizations using a variety of research strategies
- Have been doing research since 1999
- The staff consists of 9 people including 3 faculty and 6 research assistants
- Research focuses on 3 main areas (pertaining to: organizational design, human computer interaction, social psychology);
    - Multidisciplinary collaboration – performing research on the tolls and techniques for managing diverse, distant teams
    - Geographic and functional distance – performing experiments examining the effects of functional and geographic distance on teams
    - Interfaces and applications – experiments examining collaborative applications in relation to results of other experiments in the study

4. **Collaboratory for Research on Electronic Work (CREW), School of Information, University of Michigan** (<http://www.crew.umich.edu/>)

- Type of collaboration research – their research objective is to examine how people work with new technologies and how these technologies enable new ways of organizing work
- Have been doing research since the late 1990's
- The staff consists of 10 people
- Research focuses on new technologies (pertaining to: computer science, information science, cognitive science, social science);
    - Specifically, the research examines the ways in which new technologies makes new forms of work possible

5. **Center for the Study of Work Teams, Department of Psychology, University of North Texas** (<http://www.workteams.unt.edu/>)

- Type of collaboration research – their research objective is to "maximize individual, team, and organizational effectiveness through the design, development, and implementation of collaborative work systems"
- Have been doing research since 1992
- The staff consists of 9 people
- Research projects are on a variety of topics (pertaining to: Industrial/Organizational psychology), some example projects are;
    - Collaborative work group technology – a benchmarking study across industries of collaborative technologies for virtual teaming
    - Keys to measuring team performance – a study to determine the elements of an effective performance measurement system associated with more effective performing teams

6. **Center for Effective Organizations, Marshall School of Business, University of Southern**

California (<http://www.marshall.usc.edu/web/CEO.cfm?doc_id=611>)

- Type of collaboration research – their research objective is to conduct state of the art research on a broad range of organizational effectiveness issues
- Have been doing research since 1979
- The staff consists of 16 people in addition to several "affiliated" members and researchers
- Research project examples (pertaining to: organization design and effectiveness) include;
  - Organization Design – Numerous studies have explored, defined and assessed new organizational forms and corporate structures
  - Knowledge management and the design of the knowledge firm – projects are focused on the interplay between levels of analysis-how organizational practices at the individual, team, business unit, and corporate level contribute to the importing, enhancing, generating, applying and leveraging of knowledge resources
  - Team effectiveness – extensive research has been conducted identifying the critical factors promoting team effectiveness

7. **Cooperative Systems Engineering Group (CSEG), Computing Department, Lancaster University** (<http://www.comp.lancs.ac.uk/computing/research/cseg/index.html>)

- Type of collaboration research – they perform research in all aspects of systems engineering and cooperative systems with work that ranges from fundamental research in cooperative working through systems requirements engineering and systems development techniques to innovative ways of interacting with computer systems
- Have been doing research since 1990
- The staff consists of 65 people, both faculty and students
- Research project examples (pertaining to: computer science, systems engineering, sociology, human centric software design, human computer interaction, cognitive psychology) include;
  - Pattern of Interaction (PoInter) – is a project investigating the appropriateness of patterns as a means of communicating information about how users interact with each other through and around technology, with a view to informing the design process for computer systems to support the work and activities that the people are engaged in
  - Smart-Its – is a far reaching program envisioning computation embedded in the world, small-scale embedded devices that can be attached to everyday objects to augment them with sensing, perception, computation, and communication used to study collective context awareness of information artifacts

8. **Dynamics Research Corporation** (<http://www.drc.com/> and

<http://www.drc.com/NewsPubs/01/NewsRelease10_22.pdf>)

- Type of collaboration research - this company performs research in knowledge engineering, information technology, and teamwork improvement
- Research project examples (pertaining to: knowledge engineering, knowledge acquisition and management, information technology, operations research, modeling and simulation) include;
    - MedTeam contract - a program developed by DRC behavioral scientists for military and civilian hospital emergency teams based on their work with Army aircrews

Appendix B: Glossary

Cognitive Process: Process by which readers, writers, and viewers actively construct meaning as they engage with texts by organizing, selecting, and connecting information; making inferences; and performing acts of interpretation (Reading ASSIST Institute, 2002).

**Common Ground:* Foundation for mutual understanding (Houghton Mifflin Company, 2000).

Computational Models: Calculational tool that implements a set of mathematical equations designed to represent a conceptual model (International Atomic Energy Agency, 2002).

Conceptual Models:

(1) Set of qualitative assumptions used to describe a system (or part thereof). These assumptions may cover the geometry and dimensionality of the system, initial and boundary conditions, time dependence, and the nature of the relevant physical, chemical and biological processes and phenomena (International Atomic Energy Agency, 2002).
(2) Consists of a set of assumptions that reduce the real problem and the real domain to simplified versions that are satisfactory in view of the modeling objectives and the associated problem (Bear, 2000).

**Consensus:* Opinion or position reached by the group as a whole (Houghton Mifflin Company, 2000).

**Data:* Factual information (as measurements or statistics) used as a basis for reasoning, discussion, or calculation (H. A. Gleason, Jr., 2002). Data on its own has no meaning, but becomes information when it is interpreted (Lexico LLC, 2002).

Data Visualization: Presentation of processed information in a coherent and easily accessible way. Information can be presented in different forms using traditional devices such as pie charts, scatter graphs, line charts etc. (Fayyad, Grinstein, & Wierse, 2001).

**Decision:* Passing of judgment on an issue under consideration (Houghton Mifflin Company, 2000).

Decision-Making: Form of problem solving in which one tries to make the best choice from among alternative judgments or courses of action (Sdorow & Rickabaugh).

Distributed Cognition: Acknowledges that in a vast majority of cases cognitive work is not being done in isolation inside our heads but is distributed among people, between persons and artifacts, and across time (Halverson, 1994).

**Heterogeneous Teams:* Number of dissimilar or diverse constituents associated together in work or activity (Merriam-Webster, 2002).

Human-Agent Interface: A connection point that allows for the interaction between a user (Geek.com, 2002) and a software, which carries out some set of operations on behalf of a user or another program with some degree of independence or autonomy, and in so doing, employ some knowledge or representation of the user's goals or desires (Franklin & Graesser, 1996).

**Information:* Knowledge derived from study, experience, or instruction (Houghton Mifflin Company, 2000).

Knowledge Building:

(1) Process through which we increase both our individual and our common understanding (Wells, 1999).

(2) Theory of learning, which emphasizes the collaborative construction of knowledge by a group of learners (McLean, 1999).

Knowledge Elicitation: Acquiring knowledge from human experts and learning from data. The first stage is the initial understanding and structuring of the domain. The second stage is producing the working system (extract relationships between domain concepts). Finally, the system is tested and debugged. Techniques for knowledge elicitation include interviews, protocol analysis, concept sorting, goal decomposition techniques, limited information tasks, and machine learning (Newman, 2000).

Knowledge Management: is about connecting people to people and people to information to create competitive advantage (Hoyt Consulting, 2002)

Knowledge Structures: Organized sets of beliefs about the social environment that summarize, in a general (abstract) and functional way, previous direct and vicarious experience with the stimuli encountered in this environment. These knowledge structures reside in long-term memory and are thought to be organized by stimulus domain (Bodenhausen, G. V., 1992).

Knowledge Visualization: Visual explication of conceptual knowledge, which is based on understanding the domain knowledge, applying cognitive principles, exploiting the visual parameters, encoding salient features graphically, providing a useful process, and producing useful outputs (Idiagram).

Open Source Data : Factual information (as measurements or statistics) used as a basis for reasoning, discussion, or calculation (H. A. Gleason, Jr., 2002) that is of potential value, which is available to the general public (King, 1994).

Situational Awareness: Person's mental model of the current state of a dynamic environment; the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future (Endsley, 1988a)

**Team Collaboration:* To work jointly with others or together especially in an intellectual endeavor (Merriam-Webster, 2002).

Transactive Memory: Consists of the collection of individual understandings and the team mechanisms to exchange information, which update these individual understandings (Liang, Diane Wei, Moreland, Richard and Argote, Linda, 1995).

**Trust:* Assured reliance on the character, ability, strength, or truth of someone or something (Merriam-Webster, 2002).

* *Words from standard online dictionaries*

Appendix C: Conceptual Model of Collaboration

Conceptual Model of Collaboration

While conducting this state of the art review of human-human collaboration it was discovered that there does not exist a complete, empirically based, detail model of how humans collaborate in a team situation. There are various conceptual models that describe, at a very global level, the general stages humans go through during collaboration. For example Fisher's (1990) four stage Decision Emergence Theory (i.e. team orientation, team conflict, emergence of team decisions, reinforcement of team decisions) and Tuckman's (1965) four stage model of group collaboration (i.e. forming-storming-norming –performing). However, these global level models do not provide information on the detail stages, the cognitive process or the feedback loops that humans go through when trying to solve a common problem as part of a collaborative team. In addition, there is very little empirical data to support these global models across various collaborative problem-solving domains. In order to develop integrated collaboration tools, as discussed previously, it is imperative that we understand the specific collaboration stages and cognitive processes that team members go through. By understanding these stages and processes we can incorporate that knowledge into building the various tools and even use the knowledge as a framework to integrate the respective tools. Therefore, as part of this review, a complete conceptual model of collaboration was developed. This model was designed to handle both synchronous / asynchronous and collocated / distributed collaboration environments. The purpose of this conceptual model is twofold: (1) to attempt to represent all of the major stages, cognitive processes and feedback mechanisms of human-human collaboration, and (2) to serve as a starting point for an empirically based collaboration model that collaboration researchers can use and update as new results become available. The conceptual model presented in Figure 1 is based on a synthesis of the conceptual models in the literature along with technical discussions with colleagues with the goal of trying to represent the major collaboration stages, cognitive processes and feedback mechanisms. There currently is no empirical data to support this integrated conceptual model.

Conceptual Model Description

The conceptual model will initially be described at a global level and then at a more detailed level when discussing the collaboration stages, cognitive processes and feedback mechanisms. It is important to remember that global descriptions of conceptual models can be useful depending on the model's purpose. If, for example, one is interested in just describing ***what*** are the major elements of human-human collaboration, then a taxonomy or global conceptual model would suffice. If, however, you are interested in understanding ***how*** a team collaborates than a further description into the stages of collaboration would be required. Comprehending ***why*** a team collaborates the way they do requires an understanding not only the stages but the cognitive processes and feedback mechanisms as well. As discussed under the military requirements section, there is a need to understand the collaboration process, at the most detail level, in order to develop tools that effectively support team collaboration.

Earlier in this paper a ***collaboration taxonomy*** was described as a means to discuss and understand the research literature in collaboration. This taxonomy is a good starting point to identify the major areas within the conceptual model after which the collaboration stages,

cognitive processes and feedback mechanisms can be identified. As seen in Figure 1 the first block in the collaboration taxonomy is Team Communications. *Establishing conventions for communication* consists of the team developing rules for team behavior, terminologies and tools for consistent transfer of meaning, and individual mental model development. The second block, *Shared situational awareness and understanding* consists of the team coming to agreement with the facts of the situation, recognition of but not acceptance or resolution of differences or perspectives. The third block, *Collaborative Knowledge and Trust* consists of the team having a common understanding and agreement of corporate and individual goals and capabilities, being able to negotiate different perspectives resulting in deeper understanding of proposed solutions / actions, and development of trust between team members. The fourth block, *Attainment of Consensus* consists the team identifying and negotiating differences and achieving a common outcome agreed to by the complete team. The fifth block, *Validation* consists of the team testing the effectiveness of the proposed solutions / actions, revising the solutions / actions based on tests results, what –if analyses and producing final solutions / actions. The five blocks within the above taxonomy effectively describe the major areas of human-human collaboration.

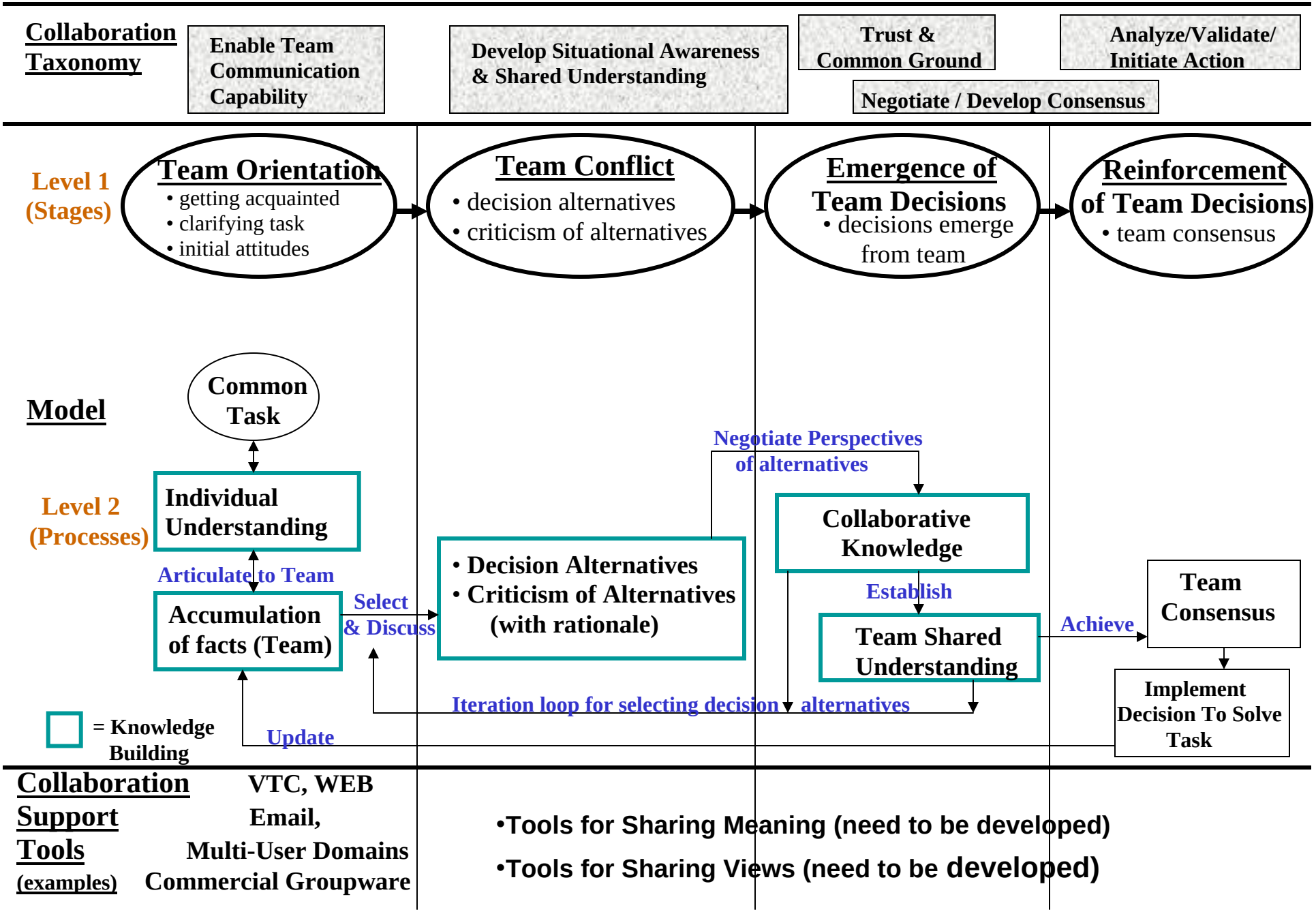
The next level in the model is the *collaboration stages* (Level 1). There are four stages of collaboration that team members go through to complete the collaborative problem-solving task. These four stages are modifications of Fisher's (1990) Decision Emergence Theory. Fisher's theory was chosen as a starting point to represent the stages because of the emphasis on cognition (i.e. compared to social behavior) and the stages capture most of the behavior within the various taxonomy blocks (e.g. team orientation with team communication, etc.). *Team Orientation* is the first stage in team collaboration, which involves team members getting acquainted, clarifying the problem to be solved, developing individual mental models based on task / team member information and establishing initial attitudes about team members. *Team Conflict* is the second stage, which involves the team coming up with decision alternatives and discussion of these alternatives. *Emergence of Team Decisions* is the third stage where decisions emerge from the team. It is important to distinguish that the decisions come from the whole team not from individuals. Trust and common ground are key in the development of team decisions. The final stage is *Reinforcement of Team Decisions* where the team, as a group, reaches consensus along with validating selected decisions / actions. It is important to realize that even though these are distinct stages and there is an implied order, the complete team or individual members may transition between any of the stages during collaboration. The collaboration pathways between stages need to be identified and validated through empirical research.

The next level is the *cognitive processes and feedback mechanisms* (Level 2), which show how and why the team is achieving their corresponding collaboration stage. For the team to go through the team orientation stage there are two knowledge building processes that team members need to perform, Establishing Individual Understanding and Accumulation of Facts (as a team). For team members to achieve individual understanding and accumulation of facts there is a *transformation process* that takes place between team members. This process is that individual team members talk to one another about the common task, which builds individual understanding along with the team, as a whole, accumulating facts. By completing the two knowledge building processes and the transformation process the team is achieving the team orientation stage behaviors (i.e. getting acquainted, clarifying task, individual mental models, etc). For the team conflict stage to be achieved, the team needs to perform one knowledge

building process involving Decision Alternatives. The team uses the knowledge gained from accumulation of facts to transform that knowledge into decision alternatives. These decision alternative are discussed and rationale provided for each alternative. To achieve the next stage, emergence of team decisions, the team needs to build *Collaborative Knowledge* and establish *Team Shared Understanding*. To build collaborative knowledge, the team transforms the decision alternative knowledge by negotiating perspectives of the decision alternatives. This results in the team building collaborative knowledge along with team decisions. The team also develops shared understanding as a result of the negotiating process. If the team shared understanding is strong enough between team members than *Team Consensus* can be achieved (i.e. Reinforcement of Team Decisions stage). If not, than there is an iteration loop for the team to select and discuss other decision alternatives and proceed through the same process cycle until team consensus is achieved. When team consensus is achieved there is also a feedback loop to update the team's accumulation of facts knowledge.

In summary, this conceptual model of collaboration is meant to facilitate discussion and research ideas among the collaboration research community. It is envisioned that through empirical testing of this model by multiple researchers an empirically based collaboration model can be derived and used to aid in the design and development of collaboration support tools.

FIGURE 1: **COLLABORATION TAXONOMY & CONCEPTUAL MODEL**



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Appendix F: Significant Publications / Conferences

Significant Publications:

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Journals:

Journal of Computer Mediated Communication (http://www.ascusc.org/jcmc)
Computer Supported Cooperative Work (CSCW) (http://www.kluweronline.com/issn/0925-9724)
Group Decision and Negotiation (http://www.kluweronline.com/issn/0926-2644)
Group Dynamics (http://www.has.vcu.edu/group/gd.html)

Significant Conferences:

Knowledge Management: When Collaboration is Essential (see slide notes), April 22-25, 2002, Ronald Reagan Building, Washington, DC
(http://www.egov.com/events/2002/km/conference/track.asp?id=2)

Workshops On Enabling Technologies: Infrastructure for Collaborative Enterprises (WET-ICE) annually since 1991

AGENTS annually since 1997

CSCW biennially since 1988

e-Gov's Annual Conference on Knowledge Management held annually since 2000
(http://www.kmpro.org/)

GROUP, ACM International Conference on Supporting Group Work held biennially
(http://www.acm.org/sigs/siggroup/conferences/group01/)

International Conference on Work Teams held annually since 1990
(http://www.workteams.unt.edu/conf/fall/fall-intro.htm)

Society of Experimental Social Psychology (SESP) Conference, held annually
(http://www.sesp.org/)

Society of Experimental Psychology's Conference on Groups, held annually since 1993

Collaboration Systems and Technologies Track of the Annual Hawaii International Conference on System Sciences (HICSS)
(http://www.computer.org/proceedings/hicss/1435/volume1/1435toc.htm)

European Conference on Computer Supported Cooperative Work (ECSCW)
(http://ecscw2001.gmd.de/)